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Pilot Plant Exploration of Slow Rate Filtration

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16. ABSTRACT

Alternatives to conventional coagulation water filtration plants (those that utilize coagulation, flocculation, sedimentation and filtration) may be appropriate for some small water utilities. One such alternative is slow rate filtration. This paper describes pilot plant studies undertaken to evaluate slow rate filtration for the removal of particulates, total coliforms, standard plate count bacteria, and organics (TOC and THMFP). Two pilot-scale filtration systems were used: a slow sand filter (operated over 800 days), and a second slow sand filter operated in parallel with a slow rate filter containing granular activated carbon media (operated over 200 days). Results from both systems will be presented.

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ABSTRACT

Alternatives to conventional water filtration plants (those that utilize coagulation, flocculation, sedimentation and rapid filtration) may be appropriate for some small water utilities. One such alternative is slow rate filtration. This paper describes pilot plant studies undertaken to evaluate slow rate filtration for the removal of particulates, total coliforms, standard plate count bacteria, and organics (TOC and THMFP). Two pilot-scale filtration systems were used: a slow sand filter (operated over 800 days), and a second slow sand filter operated in parallel with a slow rate filter containing granular activated carbon media (operated over 200 days). Results from both systems will be presented.

INTRODUCTION

Although the concept of slow rate filtration is not new, many questions concerning its application and effectiveness still exist. New analytical techniques (particle counting, improvements in turbidimetry, changes in growth media for microbiological analysis, and advances in the techniques for measuring organic constituents) now allow for a more advanced study of the filters than those of the early 1900's. The U. S. Environmental Protection Agency's Drinking Water Resarch Division (DWRD) has recently examined slow-rate filtration on the pilot scale as interest has been renewed in the application of this process for small water systems. DWRD chose to study this process for control of selected regulated inorganic, microbiological, and organic drinking water contaminants utilizing some newer techniques.

This paper will discuss two pilot-scale filtration systems: a slow sand filter (operated over 800 days) and a second slow sand filter operated in parallel with a slow rate filter containing granular activated carbon (GAC) media (operated over 200 days); i.e., a slow carbon filter. The filters were operated at rates reported to allow for biological action to occur (e.g., 0.12 m/hr).[1] The long contact time afforded for adsorption in a slow carbon filter may provide a long-term, cost-effective solution to an organic or color control problem for a small system. The paper will discuss the operating experiences and water treatment data for the two pilot filter systems and will attempt to relate this information to the operation of slow rate filters in small water systems.

SLOW RATE FILTRATION

Slow sand filtration originated in England in the early to middle 1800's. A detailed history of slow sand filtration can be found in reference 2.

The first slow sand filters in the United States were built in the late 1800's and the process is still being used in some areas. Land requirements and its unsuitability in treating high turbidity surface water led to the decline in the use of slow sand filtration by large municipalities. Small communities often followed the example set by the large municipalities and installed more sophisticated rapid sand filters. Although large amounts of land are required if slow rate filters are used to treat water for a large city (Figure 1), only 21 square meters of filter area would be required for a small community needing 100 cubic meters/day of drinking water. For small communities and other small water supply users where land is inexpensive, slow rate filters offer substantial advantages, including low capital cost (because of the use of only a limited amount of mechanical items such as mixers and valves) and lower operating costs (because chemical feed is not used).[1]

In the process of slow rate filtration, water is introduced to the reservoir above the filter media where the detention time ranges from 3 to 12 hours and some sedimentation occurs. On top of the media, a sedimentation layer (schmutzdecke) builds up which assists in filtration.

The cleaning processes begin in the water reservoir above the media where some biological action takes place. As the water enters the schmutzdecke, biological action breaks down some organic matter, and inert suspended particles may be physically strained out of the water. The water then enters the top layer of sand where more physical straining and biological action occurs and some attachment of particulates onto the sand grain surfaces takes place. Also some sedimentation occurs in the pores between the media grains where velocity is sufficiently slow.[1]

The operation of slow rate filters is relatively simple and only moderate amounts of time are needed daily to maintain the filters. Daily requirements would entail checking flow rates and head loss, measuring filtered water turbidity levels, monitoring disinfection equipment, conducting any miscellaneous sampling required, and recording appropriate data.

When the schmutzdecke layer builds up, clogging the top sand layer and causing the headloss through the filter to reach a predetermined level, the filter must be drained and the top layer of sand removed. This period of scraping is the only time during normal operation where additional manpower may be required to operate the filter. The amount of time between scrapings will depend on how much material is filtered out of the water: thus high turbidity levels would shorten the cycle.

PILOT PLANT DESCRIPTION

The pilot studies described in this paper were conducted using two separate filtration systems. Filter A was housed in a Plexiglass® box with an inside area of 0.21 m^2, and contained 0.76 m depth of fine sand on top of torpedo sand and support gravel and an underdrain system (Table 1). The underdrain system was designed for collecting the filtrate and for back filling the filter after scraping (backwashing was not a design factor). The sand used in this filter was described by the supplier as a clean "builder's" sand. It had an effective size (e.s.) of 0.17 mm and a uniformity coefficient (u.c.) of 2.1.

Filter system B was also housed in a Plexiglass® box. This system differed in that the filter box was divided in half with one side of the filter containing sand and the other containing granular activated carbon. Parallel 0.1 m^2 filters contained 0.82 m depth of media on top of support gravel and underdrains similar to Filter A (Table 1). The sand

Table 1

Pilot-Scale Slow Rate Filter Description

	Sand Filter "A"	Sand Filter "B"	Activated Carbon Filter "B"
Inside Dimension m^2(sq ft)	0.21 (2.25)	0.1 (1.09)	0.1 (1.09)
Media	Sand	Sand	12 x 40 GAC
Effective Size, mm	0.17 mm	0.29 mm	0.55 mm - 0.65 mm
Uniformity Coefficient	2.1	1.8	1.6 - 2.1
Media Depth m(inch)	0.76 (30)	0.82 (32)	0.82 (32)
Mean Reservoir Height (above media) m(ft)	1.25 (4.10)	1.09 (3.58)	1.09 (3.58)
Flow Rate m^3/day (gpd)	0.58 (152) 0.87* (228)	0.29 (76)	0.29 (76)
Loading Rate m/hr (gpm/sq ft)	0.12 (0.048) 0.18* (0.072)	0.12 (0.048)	0.12 (0.048)
Mean Reservoir Detention Time hr	10.6 7.07*	9.21	9.21
Empty Filter Bed Contact Time hr	8.69 5.79*	6.87	6.87

*Flow rate increased 50 percent at start of fifth cycle.

was a graded mix of "builder's" sand and a sand commonly used for rapid sand filtration. The mix gave an e.s. of 0.29 mm and a u.c. of 1.8. For activated carbon Filter B, a commonly available water grade GAC (12 x 40 mesh coal base) with an e.s. varying 0.5 to 0.6 mm was studied. This particle size is much larger than what is typically used for slow rate filtration media, and particulate penetration was anticipated. Thus, it was studied in parallel with sand Filter B.

Both filtration systems were fed source water from separate storage tanks with flow controlled by solenoid valves so that the reservoir level above the media varied no more than 2.5 cm on Filter A and no more than 9 cm on Filter B. This water reservoir (in addition to allowing time for sedimentation) provided the head required to force the water through the schmutzdecke, media and miscellaneous plumbing on the effluent side of the filters. When the filters were clean, the headloss through the media was low and valves were necessary to reduce the effluent flow rate to desired levels. As the headloss in the filter increased, the rate valves on the effluent streams were adjusted to maintain a constant flow rate. The parallel sides of Filter B shared a common reservoir.

Sampling ports were placed at various depths in each of the filters to allow for profile sampling. The sampling ports consisted of stainless steel tubing horizontally embedded in the media. The tubing had slots (approx. 1.0 mm width) to allow for collection of a sample from near the wall to the middle of Filter A, or from wall to wall of each side of Filter B. When these ports were used for sampling, their flow rate was kept very low (2 - 3 mL/min.) in order to avoid significantly increasing the flow through any part of the filter or disrupting the media. Samples from these ports were taken over long periods of time. The ports were also used for determination of differential head loss.

Precautions were taken to prevent shortcircuiting of water along the filter walls. Strips of Plexiglass® (6 mm) were fastened to the filter walls at two levels in the media. Both the media and the lower part of the water reservoir (above the media) were shielded from light to prevent algal growth (larger filters would not have clear walls and this problem would be prevented in normal construction).

Water for both filter systems was hauled by tank trailer to the pilot plant and stored in separate tanks for each filter system. The storage tank for Filter A was located inside the laboratory and the filter was subjected to water with a fairly constant temperature. Filter B storage facility was located outside, but the water travelled through approximately 150 meters of tubing before reaching the filter. Thus, Filter B was also not subjected to significant changes in temperature but this long transport distance lowered the turbidity between the source water and the Filter B reservoir.

A number of different water sources were used. For the first 6 cycles (intervals between schmutzdecke scrapings), water for Filter A was obtained from a local gravel pit lake (a low turbidity surface water). Raw sewage from a local municipal sewage treatment plant was added to the source water in the storage tank to provide a high coliform level (sewage to water ratio = 1/2500 V/V). For the last 4 cycles, when a higher turbidity level was desired, Ohio River water was used. For reasons explained later, gravel pit lake water was not used for Filter B. For a portion of its first cycle, low turbidity water was obtained from a local reservoir. Because coliform identification was found to be troublesome and turbidity was very low, Ohio River water was used for the duration of the study.

Filters were scraped when flow rates could not be maintained. Water influent to the reservoir was shut off and water levels were dropped to just below the schmutzdcke. The schmutzdecke and some sand, or granular activated carbon, were removed. A typical scraping removed a depth of approximately 1 cm of media. Filtered water was then pumped into the effluent side at a very low rate to avoid disrupting the media, until the media was under several centimeters of water. The reservoir was then slowly filled with raw water, and the filter put back in service. This process typically took 8 hours.

Pilot Plant Results

Particulate Control

After the initial ripening period of sand Filter A, its effluent turbidity levels were always below the 1.0 NTU maximum contaminant limit (MCL) and were routinely below 0.35 NTU during the last half of the study (Figure 2). Influent turbidity levels ranged from 0.2 to 10 NTU. Effluent samples taken after schmutzdecke scraping did not show any significant turbidity increases. After the fourth filter scraping, the flow rate was increased by fifty percent and monitoring continued. No increase in effluent turbidity levels was observed with the increased flow rate.

The turbidity reduction was also evident in particle count data. A particle counter* capable of quantifying size and distribution of particles (2.5 to 150 micrometers, (um) diameter) in an aqueous sample was used to analyze both the influent and effluent. Sand Filter A displayed 1 to 2 log reductions in cyst-sized (7 to 12 um) particle counts and tended to show greater reductions as the filter became clogged (Figure 3). Particle counts of other sizes exhibited similar reductions. Profile sampling showed only minor reductions in particle counts below the top 7 cm of sand.

After seven weeks of treating reservoir water, Filter B was switched to Ohio River water having turbidity that ranged from 0.4 to 23 NTU. This, coupled with the larger effective sizes of sand Filter B media, resulted in poorer turbidity control than observed in Filter A (Figure 4). Throughout the study, effluent turbidity levels gradually increased as the filter became clogged. After 5 cycles, the filter was ineffective for maintenance of a 1

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*HIAC Particle Size Analyzer, Model PC-320, CMH-150, Pacific Scientific Co., Montclair, CA: Mention of commercial products does not imply endorsement by USEPA.

NTU MCL. Turbidity profiles developed during cycle 6, prior to taking the filter out of service, demonstrated 1.0 NTU, or greater, at each depth sampled. The effect of excessive turbidity loading of a slow sand filter is also seen in Table 2. Cycle length decreased and start-up head loss increased while mean effluent turbidity increased with successive cycles. Clearly, the filter clogged. Even a 5 cm scraping that returned the filter to low head loss at the start of cycle 6 was short lived (Table 2).

For the period studied, granular activated carbon Filter B, with a large effective size, 0.6 mm, provided better turbidity control than sand Filter B (Figure 4). Effluent turbidities were typically below 0.5 NTU and often times below 0.1 NTU. The interval between scrapings was longer for the carbon filter than it was for either sand filter. (The scraping at 260 days was not because of loss of flow rate, rather short circuiting and formation of air pockets along the walls in the upper 10 cm required correction.)

Bacterial Control

Samples analyzed for total coliform and standard plate count bacteria were collected routinely from sand Filter A. Data showed excellent bacterial removal (Figures 2 & 3), and 4 to 5 log reductions in total coliform densities were routinely achieved after filter ripening. With the exception of one 3 week period and one later sporadic sample, coliform densities in effluent samples were less than 1 per 100 ml. Standard plate counts showed that sand Filter A lowered the bacterial counts, but the resulting data during the first 250 days were erratic (Figure 3). At this time, effluent Tygon® tubing was replaced with a stainless steel tube and

Table 2. Slow Sand Filter B Operation
e.s. = 0.29 mm
0.12 m/hr (0.048 gpm/ft^2)

Cycle Number	Cycle Start Headloss cm	Cycle End Headloss cm	Cycle Length Days	Mean Turbidity, NTU		Media Scraped cm
				Influent	Effluent	
1	1	44	98	7.6	0.59	1.0
2	3	43	62	2.4	0.63	1.0
3	6	38	40	2.7	0.73	1.0
4	10	39	28	4.5	0.77	1.0
5	24	41	6	16	2.4	5.0
6	2.5	38	16*	16	3.1	*

*filter taken out of service

effluent standard plate counts were more consistent and lower. The 7-12 um range for particulates (shown in Figure 3) suggests effective control of Giardia cysts which are typically that size.

Filter B bacterial control is seen in Figures 5 and 6. Following high counts at start-up, 1 to 2 log reductions in standard plate counts were observed with both sand and activated carbon filtration. One to three log reductions in coliform densities were typically observed with both filters. Comparing Filters A and B, better bacterial control was observed with decreased effective sand size. This was observed earlier by Hazen[3].

Dissolved Oxygen

Dissolved oxygen was monitored to be sure that sufficient oxygen was available for biological action. Recirculation of the source water (in the storage tanks) provided high oxygen levels in the raw water and oxygen was

measured in effluent samples from Filter A (Figure 7) and sand Filter B. Profile samples showed that oxygen consumption occurred in the top layer of sand Filter A. This tends to support the concept of intense biological action in the upper layer of the filter media. The mean dissolved oxygen level influent to sand Filter B was 7.85 mg/L; the mean effluent was 7.33 mg/L.

Time dependent dissolved oxygen removal by activated carbon Filter B was observed. Effluent dissolved oxygen levels from this filter ranged from less than 0.2 to 0.6 mg/L. Profile sampling demonstrated a dissolved oxygen wavefront movement through the adsorbent. Thus, a poorly oxygenated effluent would be expected for a long period of time (Figure 8). However, bacteria enumerated by standard plate count procedures were generally observed in the effluent from this low dissolved oxygen environment (Figure 5), suggesting that aerobic organisms survived their passage through this low oxygen environment.

Organic Control

During its first two cycles, Filter A was examined for total organic carbon (TOC) and 7-day trihalomethane formation potential (THMFP) control. As shown in Table 3, removals averaged 19 and 18 percent, respectively. Because gravel pit water TOC was relatively high (7.1 - 11.1 mg/L) a capillary column, gas chromatographic profile was conducted and the water found to be very heavily laden with low to mid molecular weight organic compounds relative to typical surface water profiles.[4] This was believed attributable to a nearby oil dump in the gravel pit. For this reason gravel pit water was not treated in Filter B. The reservoir water and, later, Ohio River water influent to Filter B had a lower TOC (1.5 - 3.2 MG/L). Treating these waters, sand Filter B averaged 15 percent removal of both TOC and 7-day THMFP. On a percent

removal basis, the two sand filters behaved similarly, but on a weight removal basis, sand Filter A was more effective.

Activated carbon Filter B's control of organics was very effective, but time dependent, as expected. Figure 9 illustrates mean TOC and 7-day THMFP removals of 88 and 97 percent, respectively. Periodic profile sampling demonstrated time-dependent wave front movement of organics through the adsorbent. This is seen in Figure 10 for 7-day THMFP. Similar behavior was observed for TOC.

Table 3. Organic Control by Slow Sand Filtration

	Filter A	Filter B
Sand e.s.	0.17 mm	0.28 mm
TOC Range, mg/L	7.1 - 11.1	1.5 - 3.2
% TOC Removed		
Mean	19	15
Range	8 - 31	5 - 24
THMFP* Range, ug/L	124 - 322	84 - 150
% THMFP Removed		
Mean	18	15
Range	3 - 34	8 - 24

*7-day storage, 15 mg/L Cl_2 added, pH 6.6 - 7.1, temp. = 20°C

DISCUSSION

Slow sand filtration can be effective for turbidity, particulate, and bacterial control. Post chlorination can further reduce filter effluent bacterial densities. In these pilot-scale studies, turbidity and bacterial control were generally better for Filter A using a smaller, 0.17 mm effective size, sand than for Filter B using a larger, 0.29 mm effective size, sand. Filter A, treating a relatively low turbidity water, 0.2 to 10 NTU, operated

effectively for over 800 days, whereas Filter B, treating a higher turbidity water, 0.4 to 23 NTU, at the same loading rate, became particulate-clogged and ineffective after 230 days of service. This is typical of problems encountered in the past when slow sand filters were used to treat turbid waters. When questions exist about the suitability of raw water for treatment by slow sand filtration, a pilot plant investigation should be undertaken to verify treatability before a slow sand filter plant is built.

At start-up, about 30 days were required to bring particulate and bacterial effluents down to a consistent level, as the filters slowly established an active biological zone. The ripening period also may have been long because of the time needed to flush material off new media. In these pilot-scale studies, no quality problems were observed following schmutzdecke scraping. Effluent quality was excellent very soon after the filters were started up. These pilot filters were drained to just below the schutzdecke and no load was applied to the media during scraping. A full-scale filter might take more time to recover because during its scraping, the filter is more severely stressed when water is drained from the media and the sand surface is subjected to motions of shoveling, walking, moving wheelbarrows, and perhaps mechanized media cleaning equipment.

These slow sand filters were observed to remove an average 15 to 19 percent of influent TOC and THMFP. Sand Filter A was more effective for organic control on a weight removal basis than sand Filter B. Other than the difference in organic influent loading (Table 3), this might be attributable to sand Filter B's larger effective size passing more particulates and, therefore, more particulate-adsorbed organics or because of a difference in biodegradability of the oil-laden organics influent to sand Filter A. The 15 to 19 percent

control of organics is generally poorer than the 25 to 50 percent typically seen for conventional (coagulation, sedimentation and rapid sand filtration) treatment.[5] A possible explanation for the performance of coagulation-filtration plants is the improved removal of fine particulates having adsorbed organics. Another explanation is that coagulation removes humic and fulvic substances that act as trihalomethane precursors. If these substances can survive for long times in natural waters, they are probably not a good food source for microorganisms and thus would not be removed by the biota in the slow sand filter. Thus, a small system having high THMFP and attempting to control THMs may not find slow sand filtration advantageous.

Using a readily-available 12 x 40 mesh GAC in a slow rate filtration mode allowing hours of contact time provided excellent organic control and better turbidity control than its large effective size would have suggested.[3] Without a disinfectant, with nutrient concentration via adsorption, and with reduced dissolved oxygen concentration in the lower depths of the media, bacterial control was effective. As with slow sand filtration, post chlorination would provide a second barrier to bacteria in the filter effluent. During these studies, no odor was detected in the effluent from the activated carbon filter, even though the water approached anaerobic conditions. Under full-scale conditions, reaeration may be required to ensure an acceptable finished water. For very small utilities with THM or other organic problems, slow sand filtration may not provide sufficient control. Slow activated carbon filtration may, however. More study of slow activated carbon filtration of waters of varying quality is needed in order to develop its cost and compare it to other organic control processes. Assuming a water with a THMFP similar to that studied with Filter B and THMFP movement through the carbon similar to

that observed in Filter B, GAC replacement costs would be at or below $1.20/1000 gallons depending on the concentration of total trihalomethane actually formed in a distribution system following post-chlorination. For very small utilities with TTHM problems, such GAC costs may be an acceptable alternative.

SUMMARY

Studies performed early in this century demonstrated effective particulate and bacterial control provided by slow sand filters.[3] Using current analytical techniques (particle counting, improvements in turbidimetry, and improved growth media for bacterial analysis), these pilot-scale studies demonstrated similar control. Modern organic analytical techniques have permitted investigation of organic control by slow sand filtration.

These pilot-scale studies indicate that slow rate filtration can be a relatively easily operated and effective process for small systems now confronted with non-compliance or for new small systems coming on-line. DWRD anticipates further study of these pilot-scale filters. Possible investigations include parallel study of different effective sizes of sand for organic control in the same water, parallel study of different effective sizes of the same activated carbon for particulate and organic control on the same water, parallel study of organic control by activated carbon or sand capped with activated carbon in waters of varying quality, effluent water quality problems after replacing media, Giardia cyst removal, virus removal, and cost-effectiveness analyses.

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REFERENCES

1. Huisman, C. and Wood, W.E., "Slow Sand Filtration," World Health Organization, Geneva (1974).

2. "Quest for Pure Water," American Water Works Assoc., No. 10020, Denver (1981).

3. Hazen, A., "The Filtration of Public Water Supplies," John Wiley & Sons, New York, 3rd ed. (1913).

4. Stevens, A. A., Seeger, D. R., Slocum, C. J. and Domino, M. M., "Gas Chromatographic Techniques for Controlling Organic Removal Processes," Journal AWWA, Vol. 73 (October, 1981).

5. Symons, J. M., Stevens, A. A., Clark, R. M., Geldreich, E. E., Love, O. T. and DeMarco, J., "Treatment Techniques for Controlling Trihalomethanes in Drinking Water," U.S. EPA, Drinking Water Research Division, Cincinnati, Ohio (September, 1981).

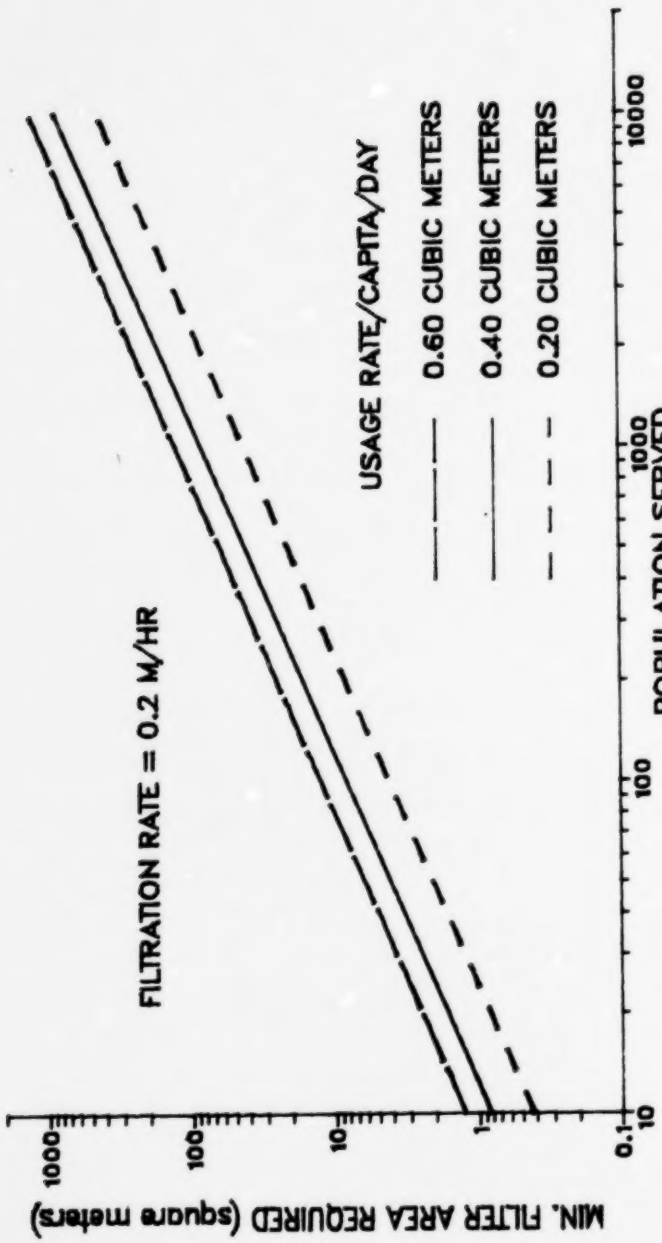

FIGURE 1. FILTER AREA REQUIRED FOR SLOW RATE FILTERS

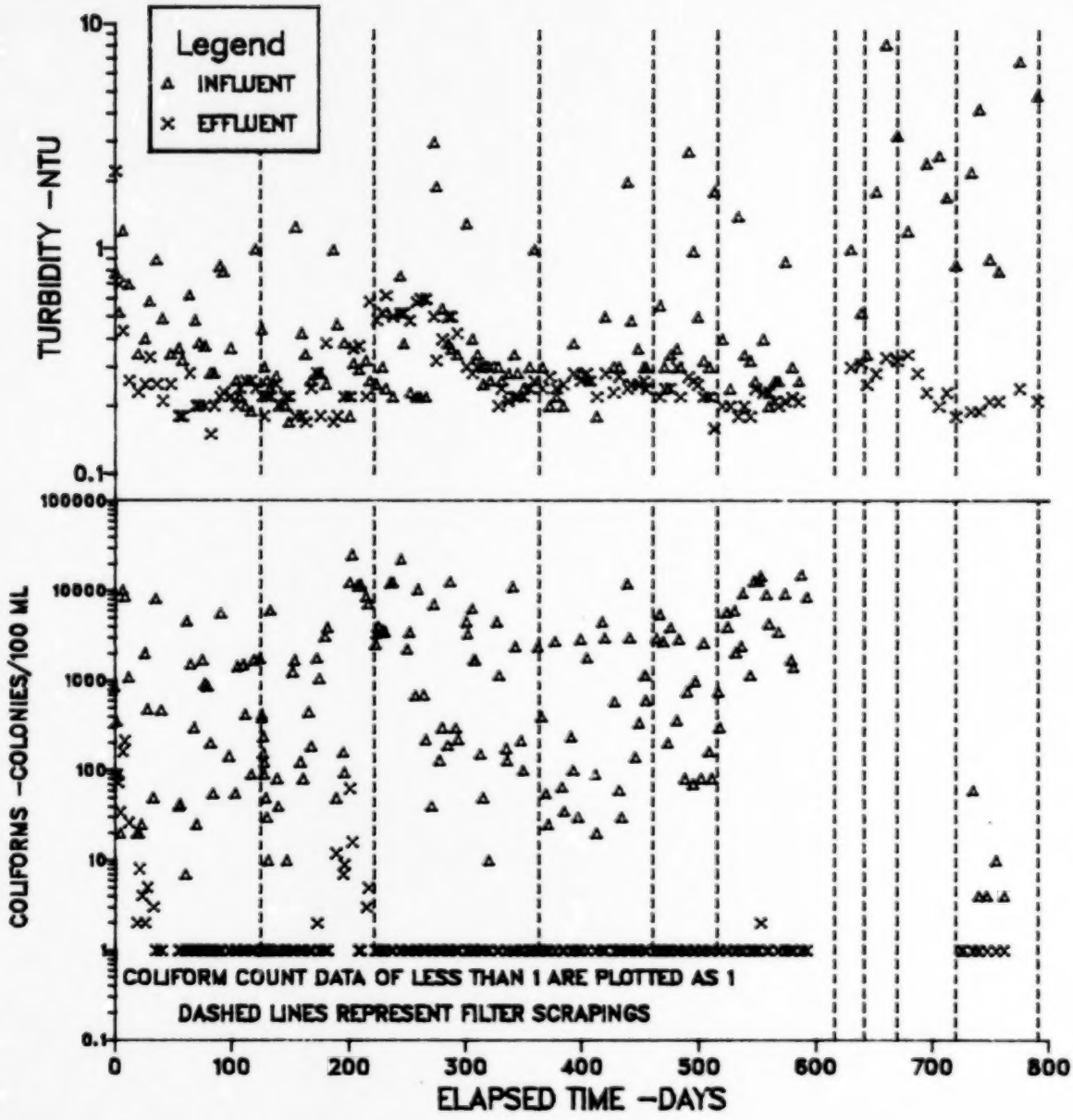

FIGURE 2. TURBIDITY AND COLIFORM DATA FOR SLOW SAND FILTER A

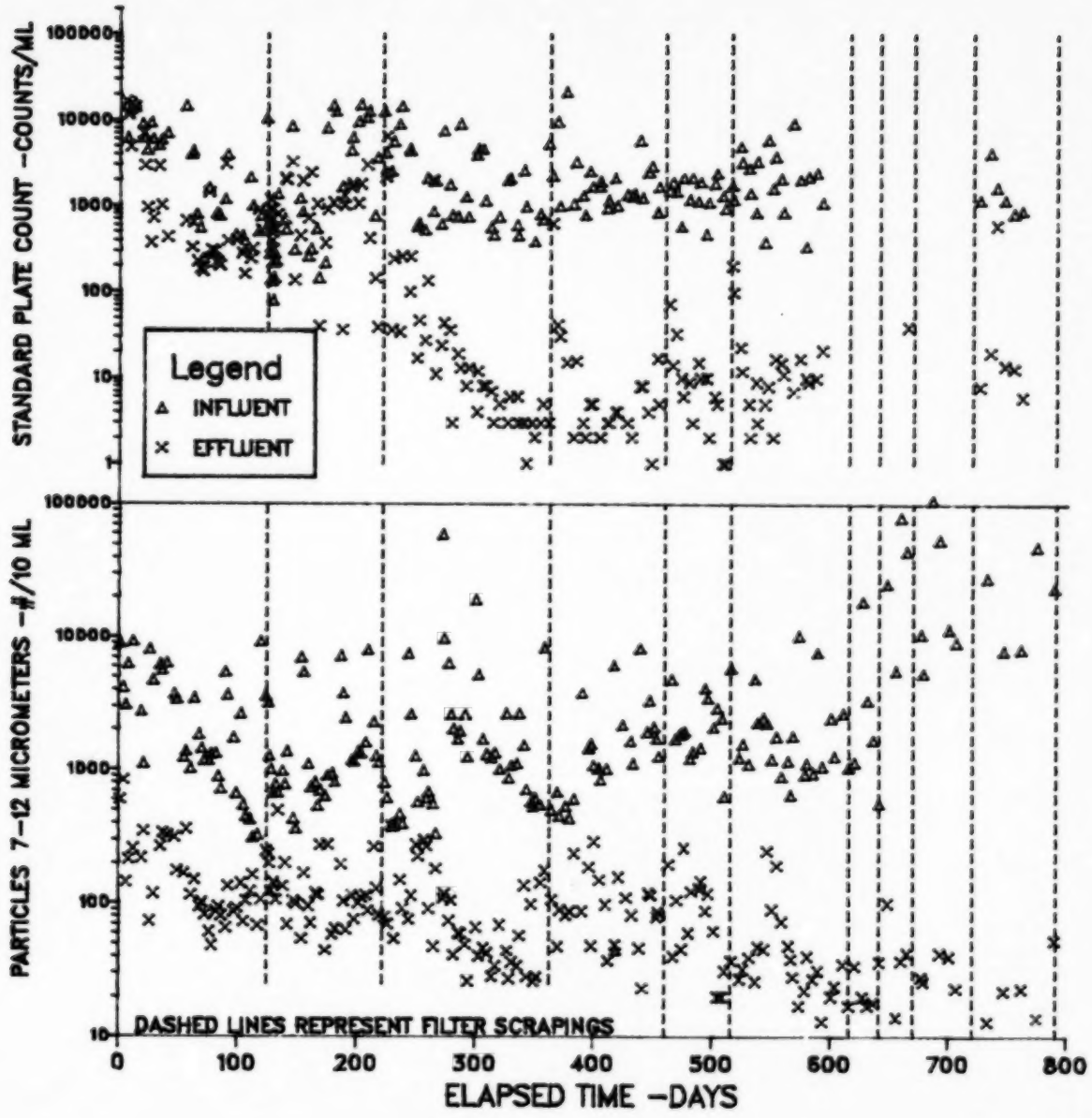

FIGURE 3. PARTICLE COUNTS AND PLATE COUNTS FOR SLOW SAND FILTER A

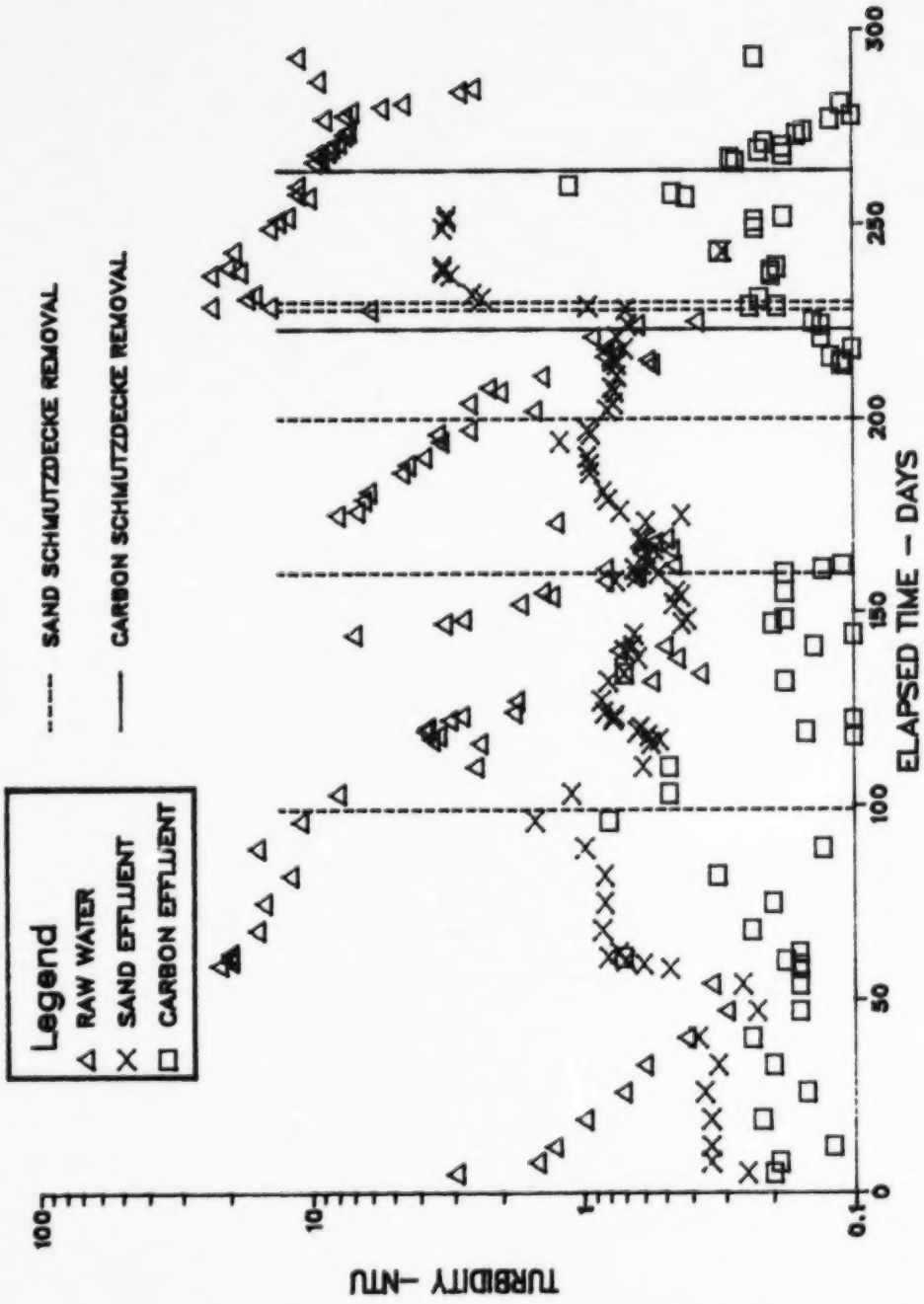

FIGURE 4. TURBIDITY CONTROL WITH SLOW RATE FILTER B

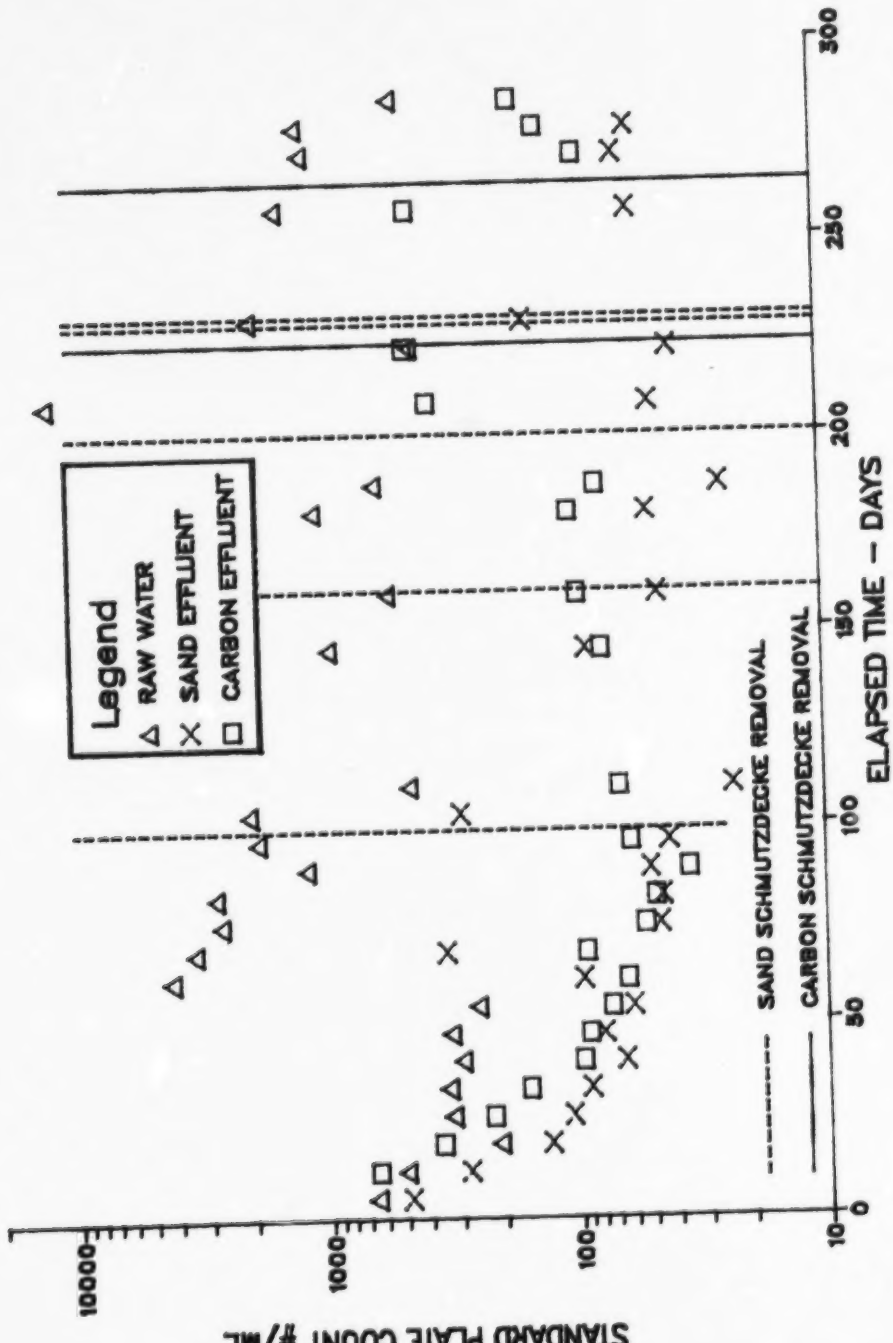

FIGURE 5. BACTERIA CONTROL WITH SLOW RATE FILTER B

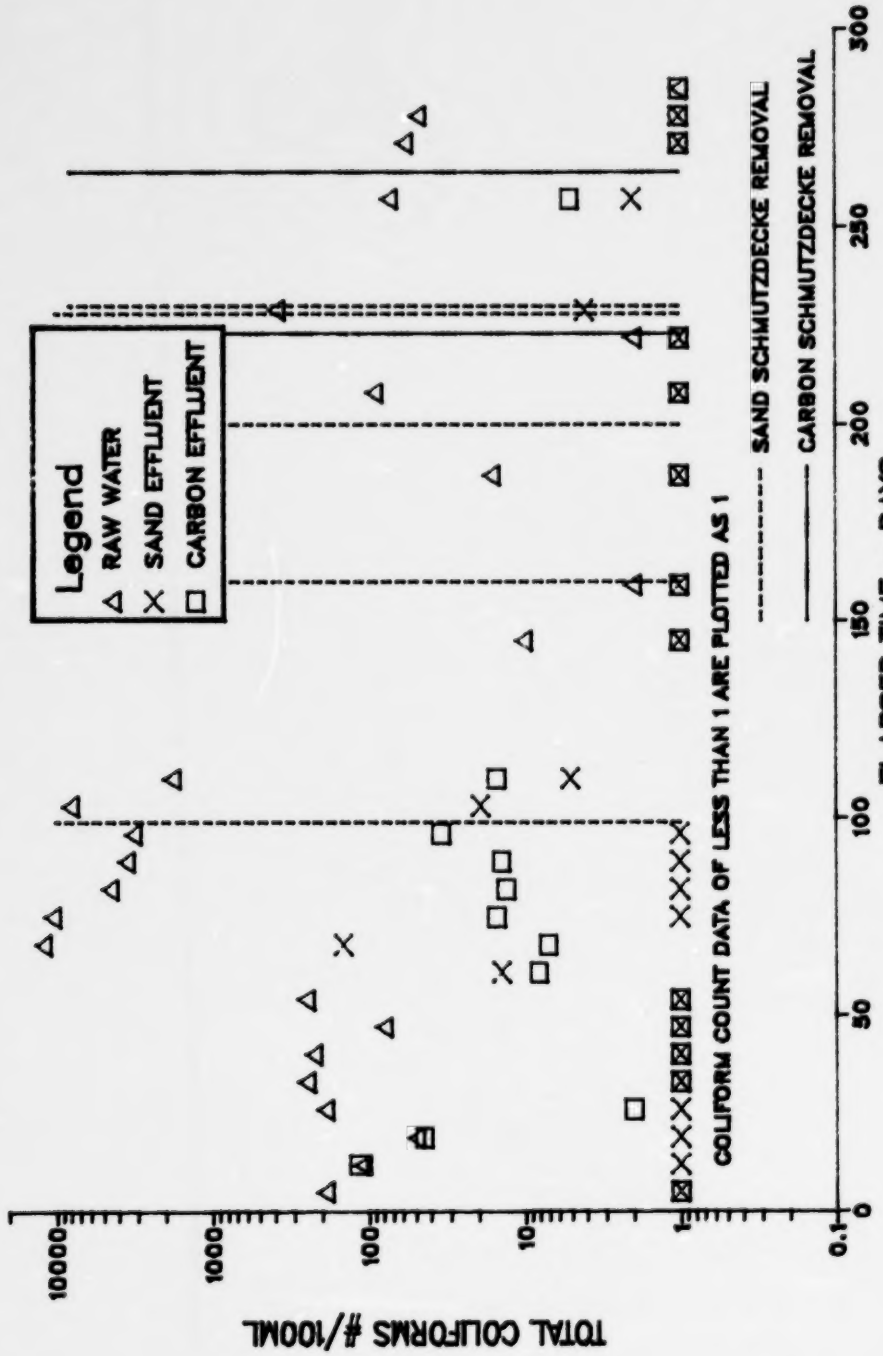

FIGURE 6. COLIFORM CONTROL WITH SLOW RATE FILTER B

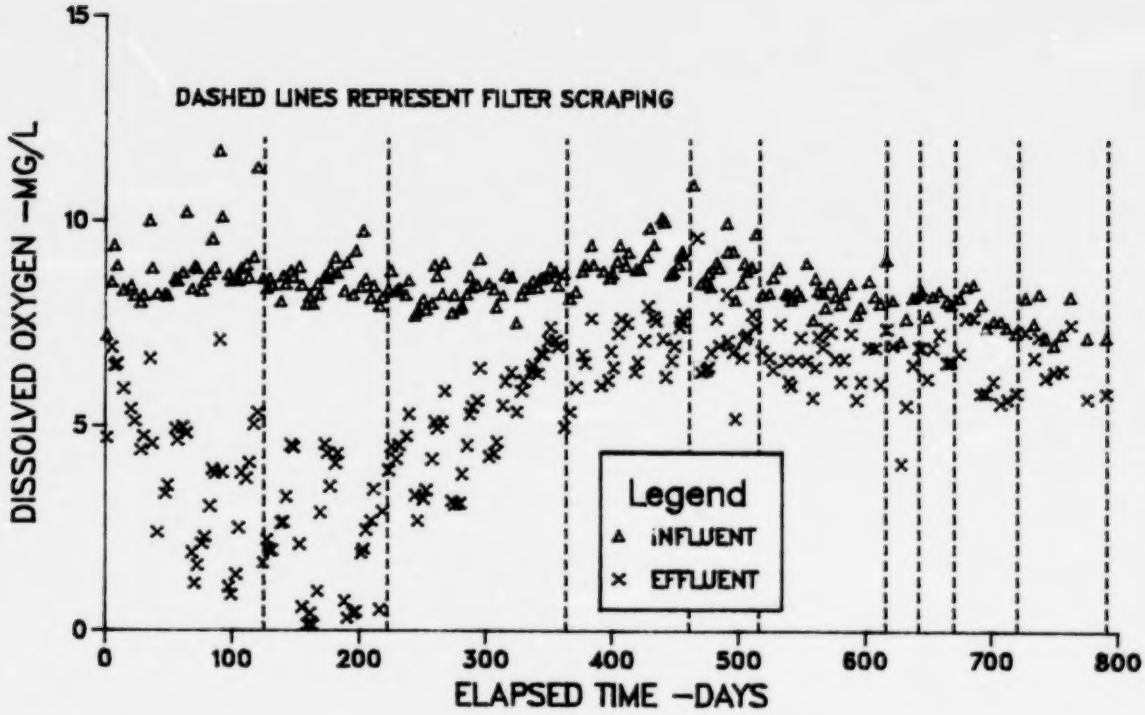

FIGURE 7. DISSOLVED OXYGEN CONCENTRATION FOR SLOW SAND FILTER A

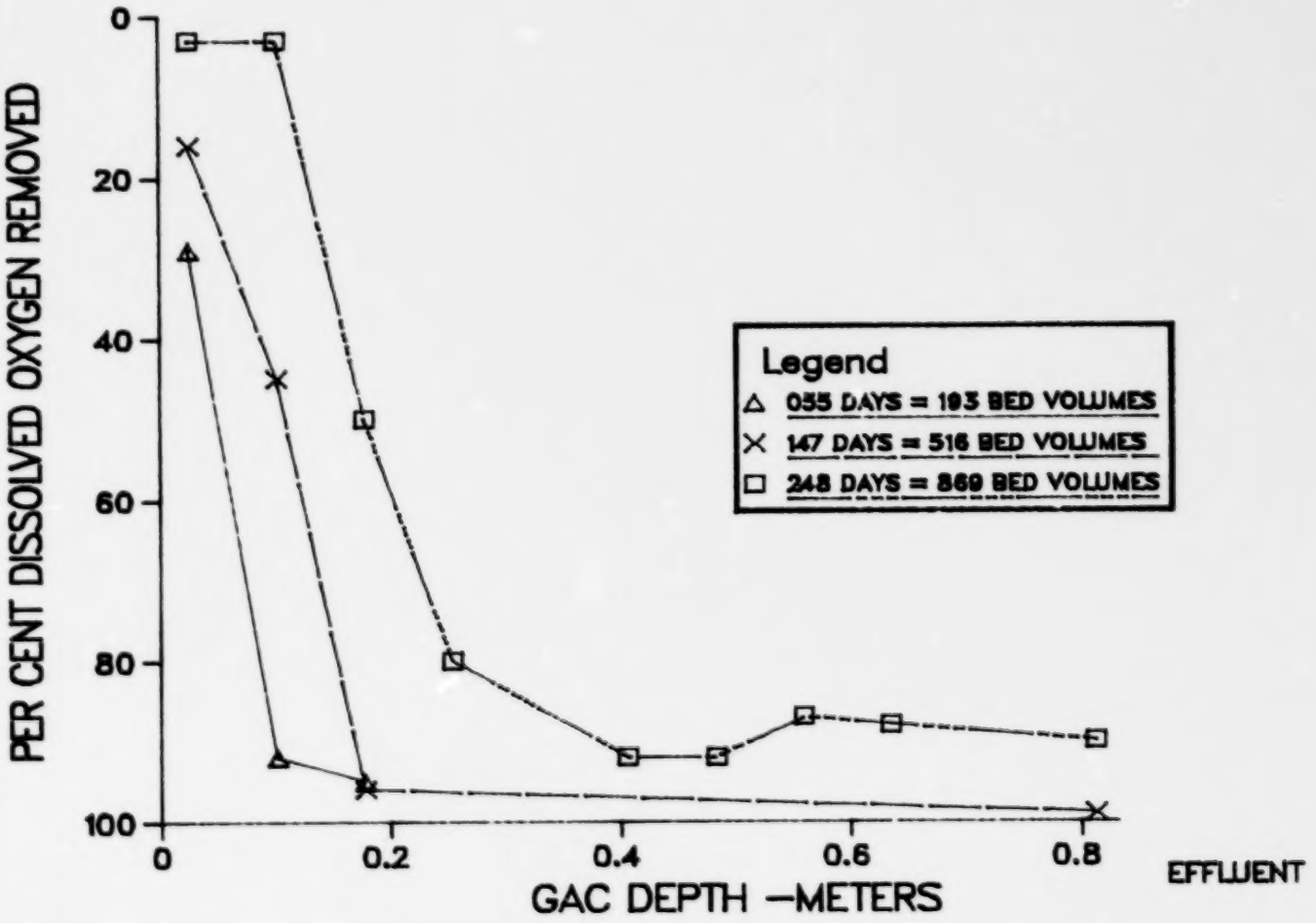

FIGURE 8. DISSOLVED OXYGEN REMOVED BY SLOW CARBON FILTER B

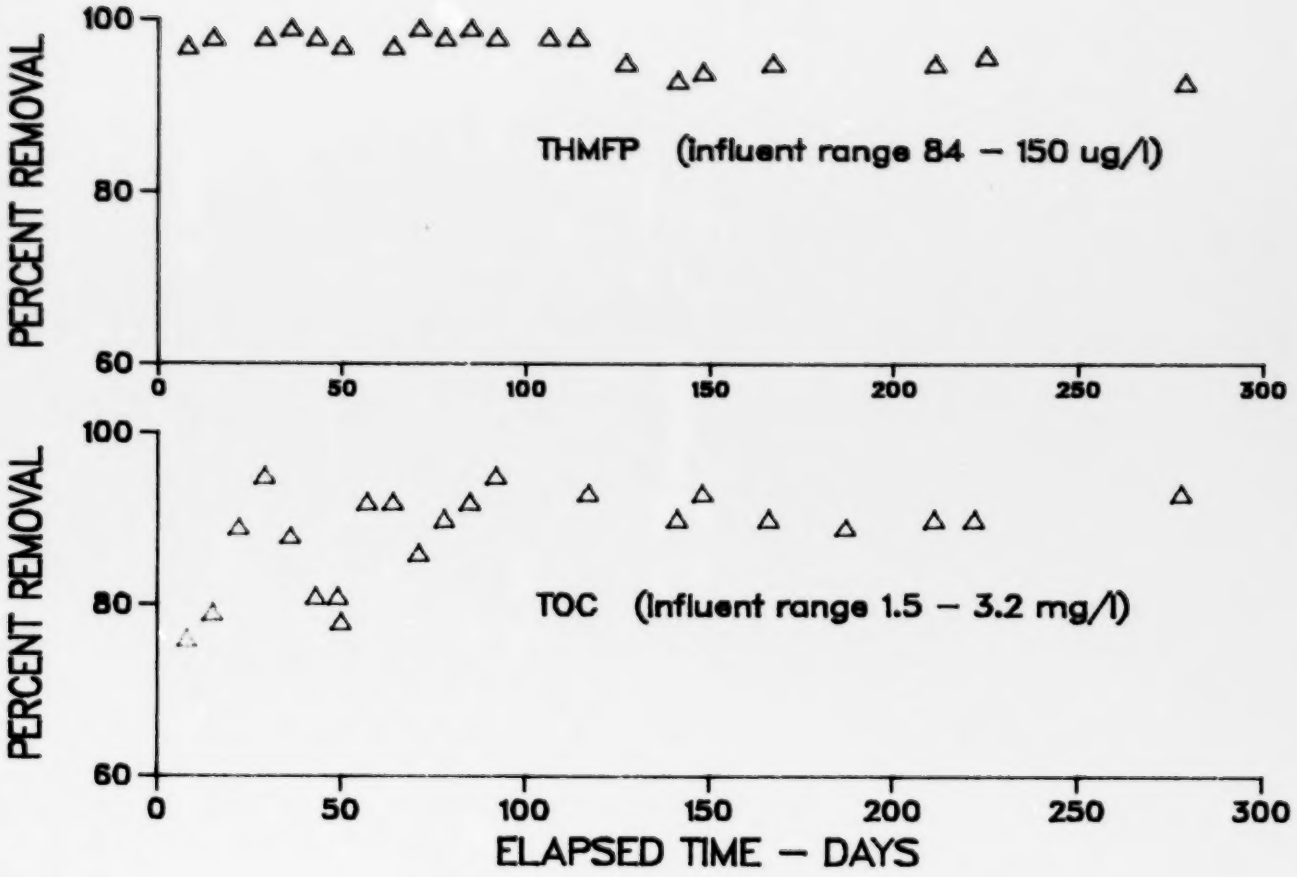

FIGURE 9. ORGANIC CONTROL BY SLOW CARBON FILTER B

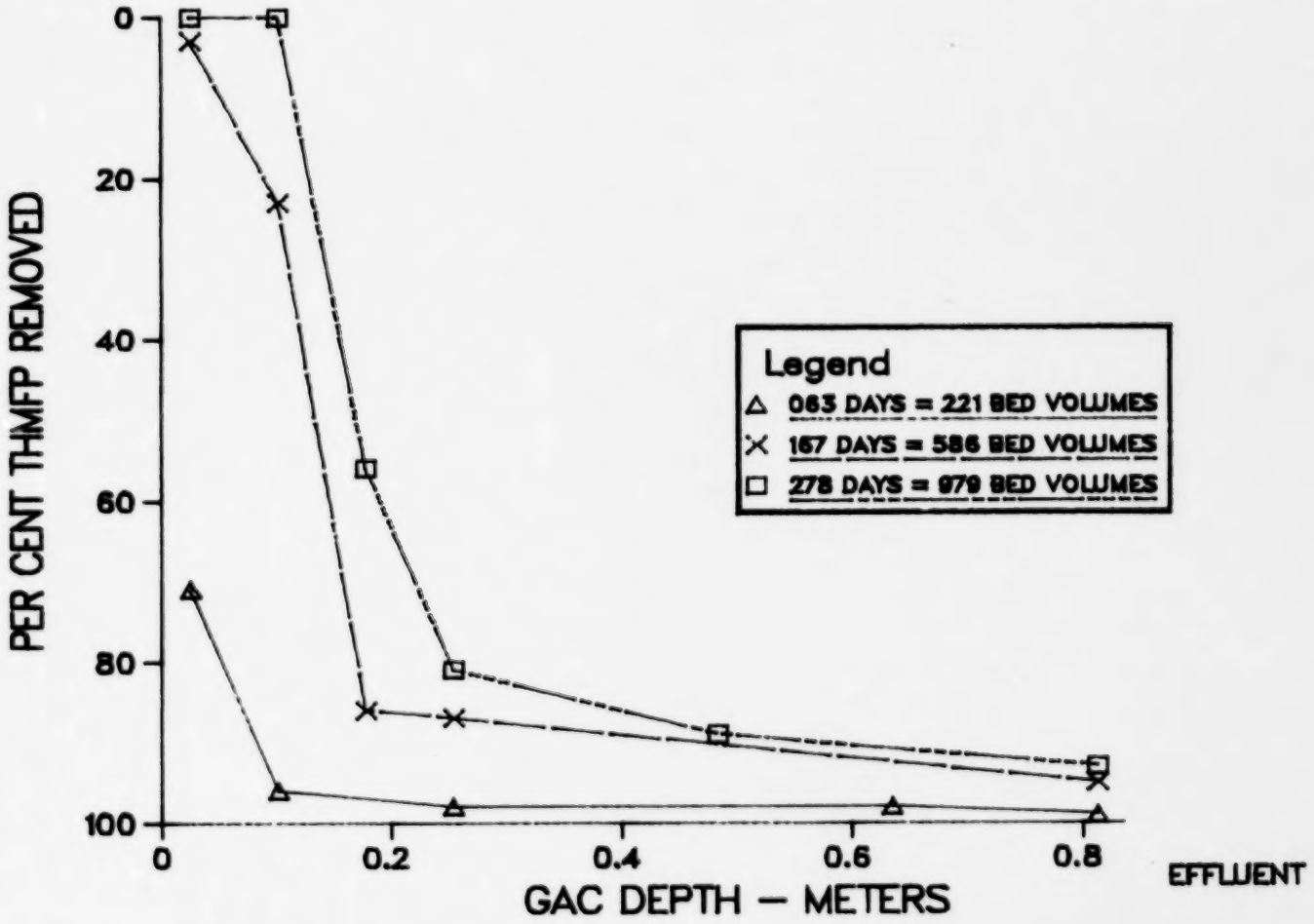

FIGURE 10. THMFP CONTROL WITH SLOW CARBON FILTER B